COMPARATIVE STUDY OF EQUILIBRATED AND UNEQUILIBRATED EUCRITES: SUBSOLIDUS THERMAL HISTORY OF HARAIYA AND PASAMONTE EUCRITES.

J. M. Schwartz and I. S. McCallum, University of Washington, Department of Earth and Space Science, Box 351310, Seattle, WA 98195-1310

Introduction: The source and duration of the heating event responsible for eucrite metamorphism is not well constrained. Three hypotheses have been proposed for the source of heat: Impact, conduction from the mantle, and rapid production of successive flows [1]. Textural and chemical relationships of non-cumulate eucrites are investigated to constrain the thermal and temporal conditions responsible for eucrite equilibration to provide insight into the evolution of the HED parent body. Pasamonte and Haraiya were chosen as they represent extremes on the metamorphic scale [2]. Pasamonte (Type 2) retains primary textures and compositions, but has been partially equilibrated during metasomatism. Haraiya (Type 7), with coarsely exsolved, partially inverted pigeonite, experienced prolonged metamorphism at subsolidus temperatures.

Analytical Methods: Sections of Haraiya (NMNH 6277) and Pasamonte (PL8966 and R89662) plus some Pasamonte and Haraiya residues were provided by NMNH. Pyroxene separates of Pasamonte and Haraiya were analyzed by EMP-WDS and TEM. Fe, Mg, and Ca WDS X-ray maps of zoned pigeonites were acquired for Pasamonte. TEM and BSE images were used to measure lamellar wavelengths.

Cryptic metasomatism of Pasamonte: Textural evidence for post-assemblage annealing in Pasamonte is best expressed in the Fe-Mg zoned rims of "unequilibrated" pyroxenes. An equilibrium Kd line was determined for this late-stage metasomatic event [3] from a linear fit to variable Wo rim compositions (Fig. 1). The equilibrium line overlaps the Pasamonte5 tie line.

Elemental profiles were calculated from X-ray maps of metasomatized rims of ferroaugite grains (Fig. 2). Fe/(Fe+Mg) compositional profiles were modeled to fit measured profiles (Fig. 3). A metasomatic duration of 3.6 years was determined, corresponding to a cooling rate of 3.0×10^{-1} °C/day

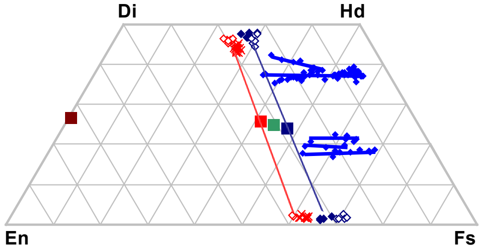

Figure 1. Blue: Pasamonte reverse-zoned ferroaugite/pigeonite. Squares: bulk comps. of Haraiya3 –red , Pasamonte5 - dark-blue, McCallister [5] - dark-red, Nord and McCallister [6] - green. Tie lines join exsolved phase compositions.

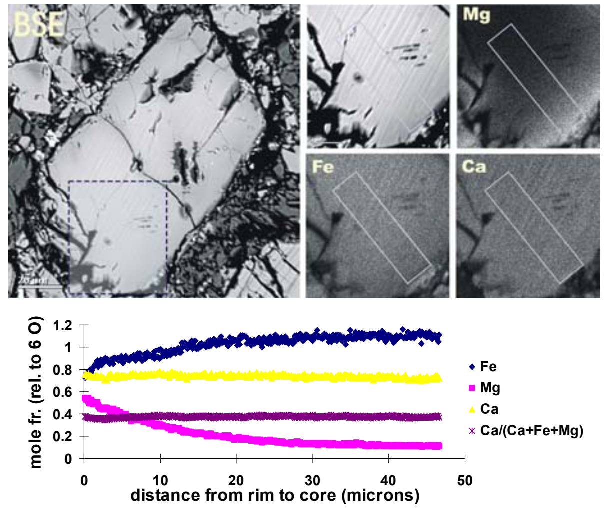

Figure 2: BSE image and WDS X-ray maps of ferroaugite clast.

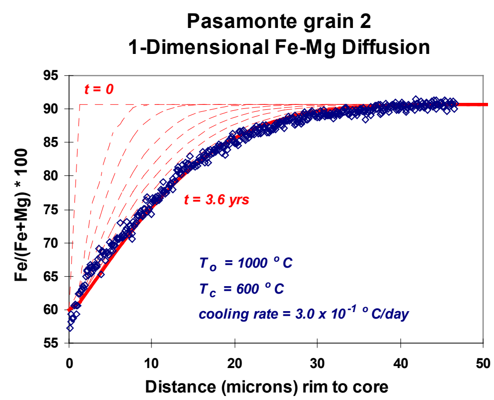

Figure 3: Measured and modeled diffusion profiles for ferroaugite.

Coarsening kinetics: To determine subsolidus annealing durations and/or cooling rates, progressive coarsening of pyroxene exsolution was modeled using a rate law which calculates progressive increase in wavelength (λ) of lamellae from an initial wavelength (λo) (Brady [4]). The time (t) required to increase λ is a function of the rate law constant (k). Diffusion at WSE (wedge shaped ends) of fine-scale, coherent exsolution lamellae is proposed as the mechanism of lamellar coarsening textures in pyroxenes. Micro-textures in eucritic pyroxenes support this model (see Fig. 5).

Brady [4] derived the rate law, $\lambda^2 = \lambda_o^2 + kt$. Pasamonte5-$Wo_{23.8}En_{26.1}Fs_{50.1}$ and Haraiya3-$Wo_{25}En_{31}Fs_{44}$ have compositions very similar to the Fe-rich experimental composition of Nord and McCallister [6]. Values for k at 1300ºC, 1200ºC and 1100ºC for the Fe-free composition were determined by Brady [4]. k at

T<1100°C was determined by a fit of the data at known T on a graph of ln*k* vs. 1/T (Fig. 4). Coarsening is ~10 times faster in the Fe-rich composition than the Fe-free at the same temperature Nord and Gordon [7]. Thus, *k* values for Pasamonte and Haraiya pyroxenes at temperatures applicable to this study (1050°C-700°C) will be an order of magnitude greater than those determined from the extrapolated line in Fig. 4.

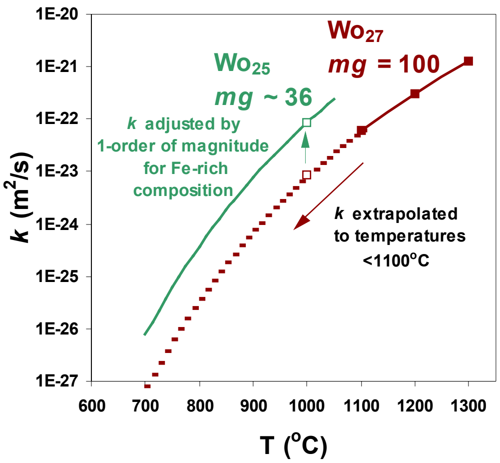

Figure 4: Rate law constant vs. T for Fe-free composition (dark-red). Solid squares - experimental data. Dashed dark-red line – extrapolated *k* values. Green line - *k* values for Fe-rich composition Nord [6]

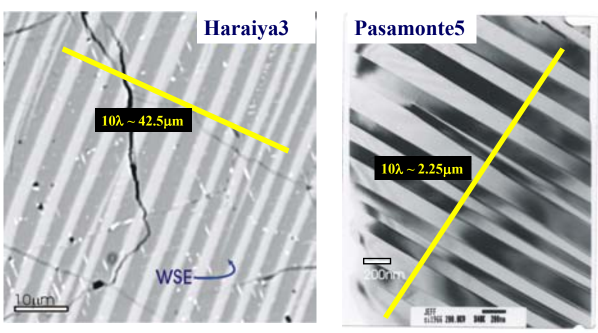

Figure 5: BSE and TEM images of Haraiya3 and Pasamonte5. Measured values for λ. Note WSE structures in both pyroxenes.

Measurement of lamellar wavelengths in pyroxene, 22 nm for Pasamonte5 and 4.25µm for Haraiya3 (Fig. 5), permitted annealing durations to be modeled. Evolution of lamellar wavelength as a function of annealing time is shown in Fig. 6. For Pasamonte5, primary cooling (0.1°C/hr, Walker et al. [8]) of event **1** in Fig. 6 was followed by mixing and reassembly. Assuming cooling from ~1000°C to 600°C (event **2**), coarsening of lamellae to the final wavelength of 225 nm required ~60 years. This corresponds to a cooling rate of 1.3 x 10^{-2} °C/day, which is an order of magnitude slower than that calculated from the modeled rim compositions. This discrepancy may be due to using opx diffusivities. Pigeonite diffusivities are unknown but are believed to be ~10x slower than opx. Equilibrated Haraiya3 (event **3**), requires ~25,000 years or a cooling rate of 3.4 x 10^{-5} to evolve λ to 4.25µm.

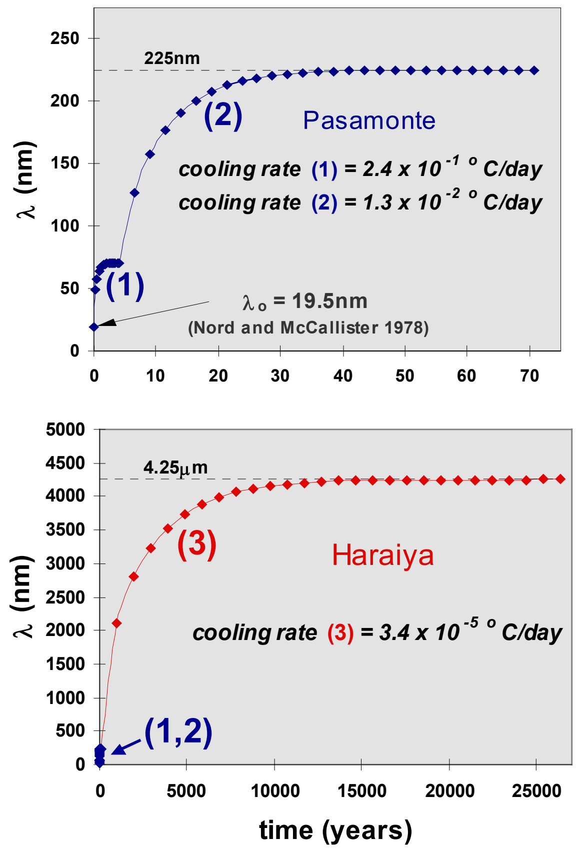

Figure 6: Evolution of λ over time for Pasamonte5 and Haraiya3. Pasamonte5: (1) Primary cooling (2) Post-assembly annealing. Haraiya3: (1,2) for scale, (3) Annealing during metamorphism.

Conclusions: Assuming that Pasamonte and Haraiya define extremes on the metamorphic scale, the variation of textures in basaltic eucrites may be explained by a range in the duration of subsolidus annealing of 3 orders of magnitude. If 25,000 years defines the upper limit of metamorphism for basaltic eucrites, mechanisms for the heat source and thermal evolution of the basaltic crust need to be reevaluated.

References: [1] Yamaguchi et al. (1996) Icarus 124, 97. [2] Takeda and Graham (1991) Meteoritics 26, 129. [3] Schwartz et al. (2002) LPSC XXXIII, #1846. [4] Brady (1987) Am. Min. 72, 697. [5] McCallister (1978) CMP 65, 327. [6] Nord and McCallister (1979) GSA abst. 488. [7] Nord and Gordon (1980) GSA abst. 492. [8] Walker et al. (1978) PLPSC 9, 1369.